GLOBAL CLOUD COVER FOR SEASONS USING TIROS NEPHANALYSES

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ABSTRACT

TIROS nephanalyses are used to obtain global maps and latitudinal profiles of average cloud amount for the four seasons for the year March 1962 through February 1963. It is found that the gross patterns and season-to-season variations of these cloud distributions bear a striking resemblance to corresponding features of normal cloudiness, although there are some differences which call for further study. In many cases anomalies in cloudiness can be related to corresponding anomalies of the general circulation.

In considering the *magnitude* as distinct from the *pattern* of cloudiness, there is some suggestion that during the chosen period the TIROS nephanalyses gave too much cloudiness for large cloud amount, and too little for small cloud amount.

1. INTRODUCTION

In certain studies of the general circulation and in long-range forecasting there is a need for routinely prepared global fields of meteorological quantities averaged over months and seasons. Up to the present time these have been confined largely to fields of geopotential at various levels together with derivatives, such as geostrophic winds and fields of mean "thickness" or temperature in deep layers of the atmosphere.

The availability since April 1960, of information from the TIROS weather satellites naturally encouraged attempts to construct charts of global mean cloud cover (e.g. Arking [5]), especially since at the same time as these data became available, several groups were seriously working on dynamical models of the general circulation containing sources and sinks of thermal energy.

Several recent studies have provided quantitative evidence of the importance of clouds in the radiative heat budget of the atmosphere. For example Namias [8] has shown how an abnormally large amount of cloudiness in the winter of 1962–63, by trapping the normally large radiative losses, may have helped preserve for several months the heat content of an extensive warm pool of water built up during the previous summer in the North Pacific. This warm pool was the site of abnormally large sensible and latent heat transfer from the ocean surface during the winter, which had far-reaching effects on the broadscale circulation.

A thermodynamical model has been developed for specifying and predicting mean seasonal temperatures in the atmosphere and at the earth's surface (Adem [1]). In this preliminary model, the cloud structure has been simplified so that only cloud amount appears as an independent parameter. Tests with this model (Adem [2]) show that the predicted temperatures are very sensitive to cloud amount, for a change of only one-tenth in cloudiness leads to changes of several degrees in surface temperature. Therefore it is clear that knowledge of observed mean seasonal cloud cover will be useful not only in testing the modeling assumptions, but also in simulating cloud amount so that this quantity can be generated within the model.

To assist in studies of this kind, an attempt was made to obtain global mean seasonal cloud amount (mean daytime cloudiness only) from TIROS cloud pictures. It was decided at the outset not to deal with cloud type, since this is more difficult to obtain.

The immediate objective of this report is to point out the valuable results which can be obtained in spite of seemingly inadequate data. The particular procedure and source of data used are not recommended for routine processing of TIROS cloud information.

2. PROCEDURE

Unfortunately, no daily charts of cloud cover were available from which seasonal means could be summarized, despite attempts to obtain daily "mosaics" extending over as much as one-third of a hemisphere from the TIROS photographs (Oliver [9]). Therefore it was decided to make use of the TIROS nephanalyses (U.S. Weather Bureau [11]) which are transmitted each day to practicing meteorologists, and have an important advantage over the original photographs in that they contain an estimate of cloud amount made by experienced meteorologists at the readout stations. A complete file of these nephanalyses was kindly made available by the Weather Bureau's National Weather Satellite Laboratory.

Briefly, the procedure used consisted simply of tabulating the cloud amount from all available nephanalyses for a given season at each 5° intersection of latitude and longitude between approximately 60° N. and 60° S. latitude,

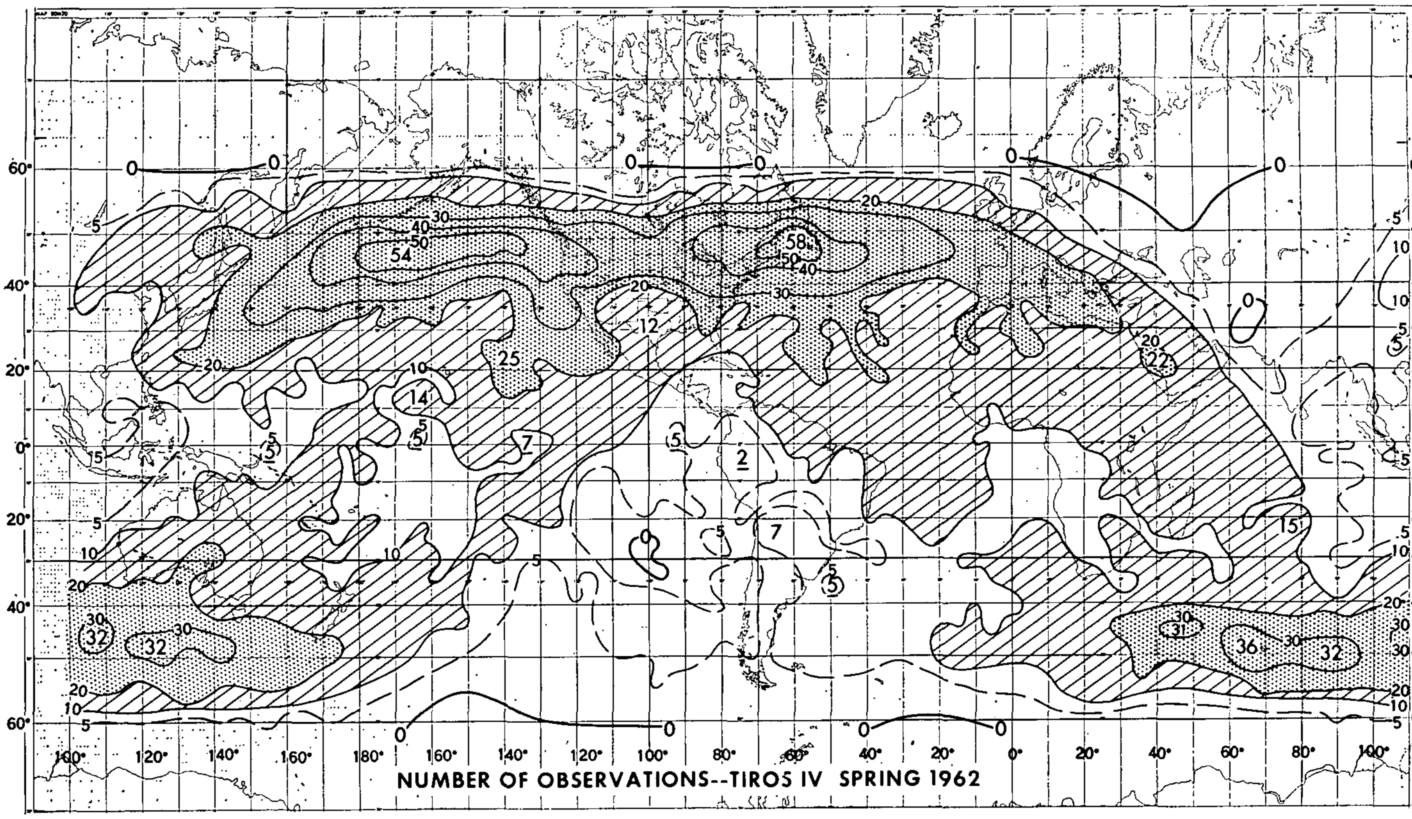

FIGURE 1.—Number of TIROS IV nephanalyses at each 5° intersection of latitude and longitude during the season March–May 1962.

and obtaining an average. The resulting means can be treated in different ways; e.g., they were plotted and analyzed to obtain maps of global mean cloud cover (figs. 7 to 10, middle). Four seasons were chosen, from March–May, 1962, to December–February, 1962–63.

To give some idea of the large amount of data which was processed, it may be mentioned that of the 700 nephanalyses utilized for the season March–May, each was constructed from a mosaic of from 1 to 16 individual TIROS photographs (average about 10); approximately 7,000 individual photographs were indirectly utilized in this season alone.

In spite of this large supply, the data seem inadequate for the purpose at hand, since, as the result of known limitations of the TIROS system, the data are poorly distributed in space and time. Figure 1 is an analysis of the total number of individual nephanalyses available at each 5° intersection of latitude and longitude for March–May. This number varies from practically zero over large parts of Asia and eastern South Pacific Ocean to a maximum of 58 in the Gulf of St. Lawrence. If we assume that approximately one observation a day is essential to define adequately the mean daytime cloudiness (the exact number depends of course on the temporal stability of the cloud cover), then we see that only in limited areas of the North Pacific and North Atlantic Oceans do the available data approach 50 percent of this minimum.

The data are also poorly distributed in time. Thus, in the regions of maximum data coverage in the Northern Hemisphere, 60 percent or more of the observations were in April, while in the corresponding regions of the Southern Hemisphere (south of Australia and in the southern Indian Ocean), 60 percent or more were in March, or in March and May.

The analyses of the number of observations for the other three seasons are not shown. For June–August and September–November the pattern of observations was similar to that of March–May. During December–February, the greatest concentration of observations appeared at lower latitudes (30°–40° N. and 10° S.), and in this season there were less than 5 observations at any intersection south of 40° S., except south and southwest of Australia (about 10 to 15 observations). In all seasons except March–May a few usable observations appeared at 65° N. and S., because the inclination of the orbit was changed from 48° for TIROS IV to 58° for TIROS V and VI.

The number of observations varied greatly from season to season, being greatest in September–November (maxima, 67 in the Northern and 81 in the Southern Hemisphere) and least in June–August (maxima, 39 in the Northern and 25 in the Southern Hemisphere). This was due in part to variations in the satellite launching schedules and in their useful lifetimes. Nephanalyses were available as follows during the chosen year of study:

TIROS IV, March 1 to June 9; TIROS V, June 19 to February 28; TIROS VI, September 18 to February 28. It will be noted that no observations were available for June 10 to June 18, inclusive, and only December–February had two operational satellites during the entire season. In spite of this, December–February came close to June–August in paucity of observations (maxima, 52 in the Northern and 29 in the Southern Hemispheres).

The distribution of the number of observations from month-to-month within each season varied greatly with location and season.

Without doubt, this inadequate data coverage is the greatest single source of error in estimating the mean seasonal cloud amount, and far overshadows such difficulties as that of interpretating the satellite photographs (to be treated later).

The particular method used for extracting cloud amount from the nephanalyses is illustrated in table 1. The first row contains the seven symbols used on the nephanalyses, the second row the corresponding seven-digit code used in the computations. The approximate range of cloudiness in octas for each code number, shown in the third line, is obtained from the international definition of the symbols. The last line shows the average cloudiness in percent of sky cover. The mean cloud cover was obtained by converting the seasonally-averaged code number to cloud amount in percent, using the last line of the table.

There are two obvious faults inherent in this procedure. The first results from the pronounced overlapping in the range of cloudiness for adjacent symbols. This difficulty is evidently more apparent than real; for, in accordance with personal communication with Col. James Jones in charge of the TIROS nephanalysis program, the range in octas actually used in practice at the readout stations was considerably less than that in table 1, eliminating most of the overlap.

The second fault is that the scale is not linear in cloud amount, so that a pair of code numbers appears close together in both the upper and lower range of the scale. Tests with typical cloud-amount distributions suggest that this has the effect of systematically overestimating cloud amount when the actual cloud cover is large, and vice versa for small cloud cover. However, the magnitude of this bias for the range in mean cloudiness found in this study is less than 5 percent.

The cloud code used for more recent TIROS nephanalyses has been changed to eliminate the overlap, but unfortunately it is still non-linear and has been reduced to four digits. In the author's opinion, it would be better, for studies of mean cloudiness, to use a linear 5-digit code having class intervals of 20 percent cloud cover.

TABLE 1.—*Percent sky cover from symbolic nephanalysis code for TIROS IV to VI*

Symbol	C	CvS	S	SvB	B	Bv⊕	⊕
Code	1	2	3	4	5	6	7
Range (8ths)	0	0–4	1–4	1–7	5–7	5–8	8
Average (percent)	0	25	31	50	75	81	100

3. DISCUSSION OF RESULTS

MEAN SEASONAL CLOUD COVER OVER THE UNITED STATES

A comparison of the cloudiness over the United States averaged from TIROS pictures with that obtained from official Weather Bureau hourly surface observations from sunrise to sunset (based on about 150 stations) is shown for the four seasons in figures 2 to 5. In view of the poor space-time distribution of TIROS observations, we must consider the agreement in pattern even in some of its minor details fairly good in most areas. Figure 1 shows that in spring 1962, the maximum number of observations over the United States was only about 50. Over Texas this decreased to about 12. The average number of observations was even less for summer and winter. Therefore it is clear that we must attribute the fair agreement in pattern to a certain stability throughout the season in the cloud distributions, perhaps the result of the persistent recurrence of preferred circulation types.

An exception to the pattern agreement is to be noted in the northern areas of the Great Basin and Rocky Mountains. Here the TIROS-derived mean cloudiness appears to be consistently much less than that reported by the ground observer.

The pattern agreement in fall is poorer than that of the other three seasons, particularly in the northern Great Plains, in spite of the larger number of observations (ranging from 62 in the Middle Atlantic States to 28 in Texas and Nevada). This poor agreement is due partly to the fact that 50 percent or more of the observations were in September.

The agreement in absolute magnitude of cloudiness is not as good as in pattern resemblance. This is clarified in figure 6, where values of surface-measured cloud cover (interpolated to each 5° latitude-longitude intersection over the U.S.) are plotted against the corresponding TIROS values for each of the four seasons. The correlation between the two cloud estimates is fair, especially in winter, in agreement with the subjective comparison of spatial patterns. However, a systematic difference in magnitude is evident, whereby the TIROS-derived cloudiness average is less than that of the ground observations, especially for small cloud amount, and systematically larger for large cloud amount. This is consistent with what is known about the difficulties of estimating cloudiness both from TIROS photographs and from ground observations (Erickson and Hubert [6]). From data published in the report of Erickson and Hubert it is also clear that the average negative bias is consistent with results of simultaneous comparisons of individual TIROS and ground observations.

No attempt will be made here to ascribe the systematic

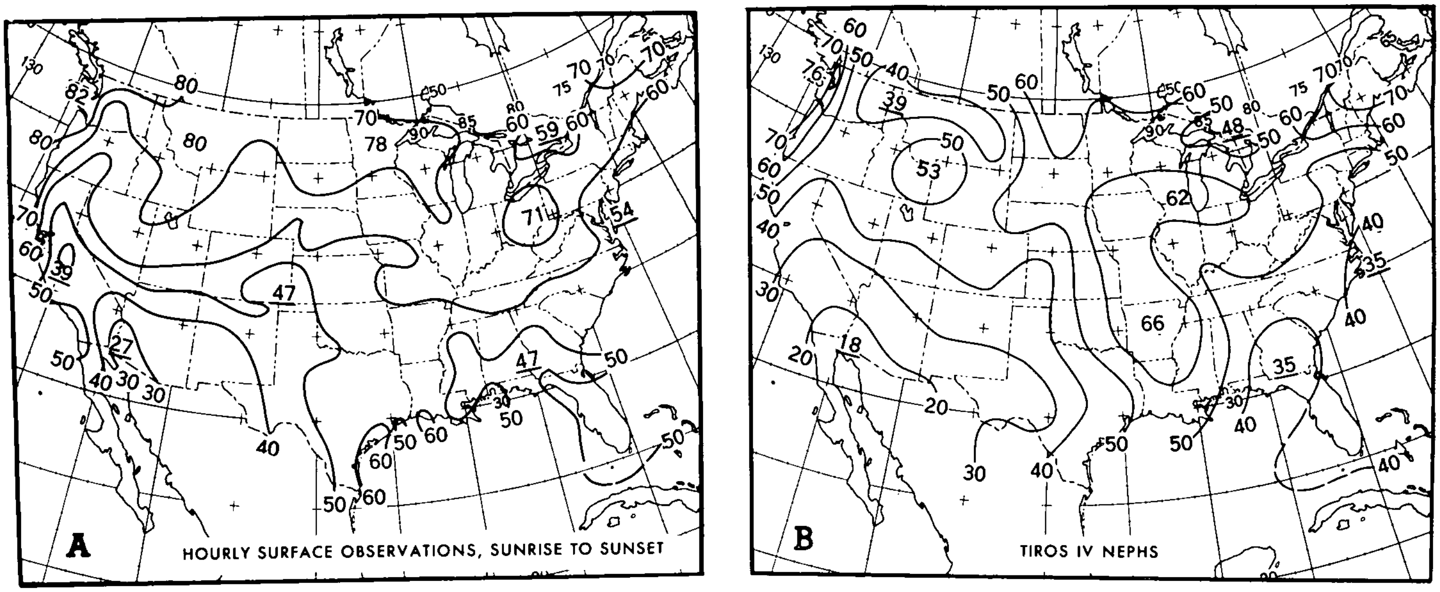

FIGURE 2.—Average daytime sky cover (in percent) for March–May 1962, over theUnited States from hourly surface observations (A) and from TIROS nephanalyses (B).

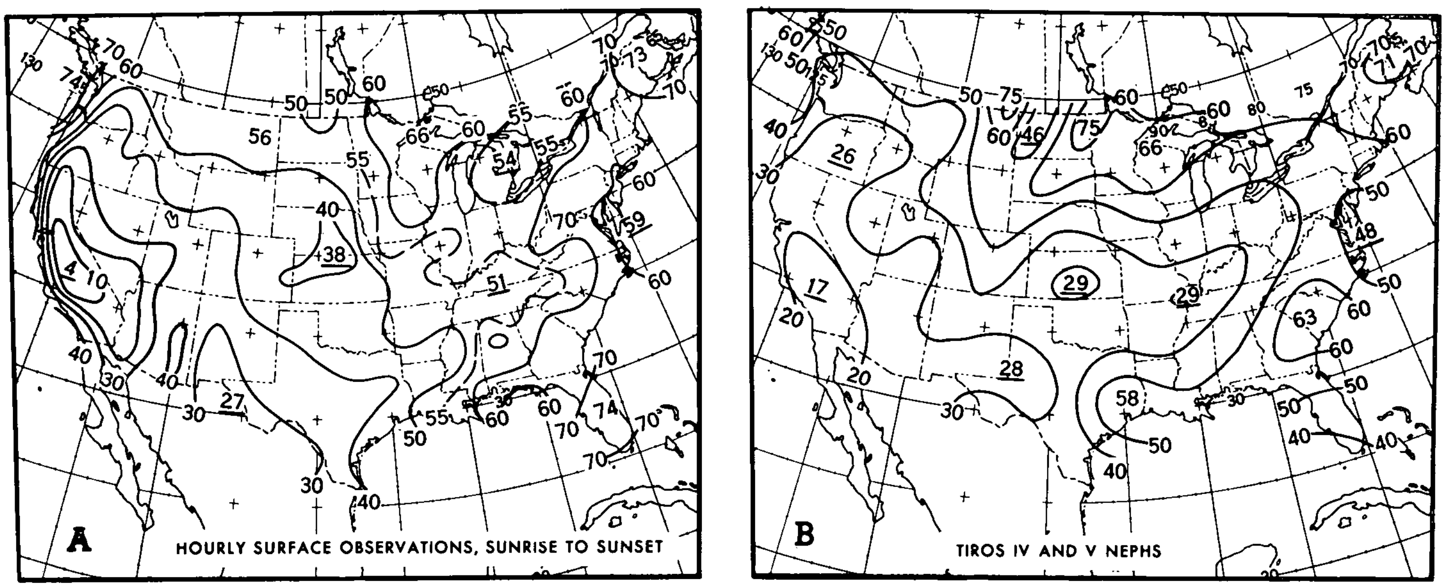

FIGURE 3.—Same as figure 2, for June–August 1962.

differences shown in figure 6 to an error in one or both of the two observing methods. However, it is clear that the scatter of points must be due to large *random* errors in the TIROS-derived mean cloudiness caused by insufficient and poorly distributed observations.

GLOBAL PATTERNS OF CLOUD AMOUNT

The global patterns of mean cloudiness constructed from TIROS data are shown in the middle part of figures 7 to 10. These have been analyzed subjectively by heavily smoothing the plotted data. These patterns may be compared with one of several available estimates of normal (i.e., average of many seasons) cloudiness (Landsberg [7]), shown in the upper part of each figure.

For most parts of the globe the number of available TIROS nephanalyses is even lower than over the United States. Therefore it is surprising to note the overall agreement with the gross features of the normal cloud cover. Attention is directed to the cloud systems associated with the oceanic storm tracks, the major desert areas of the world, the oceanic anticyclones, and the intertropical convergence zone; all of these show general agreement in location, pattern, and seasonal migration with their normal counterparts.

A feature worthy of special mention is the broad area of low cloud amount near the equator in the Pacific Ocean, present in all seasons. In both the TIROS and normal data this region has lower cloudiness than any of

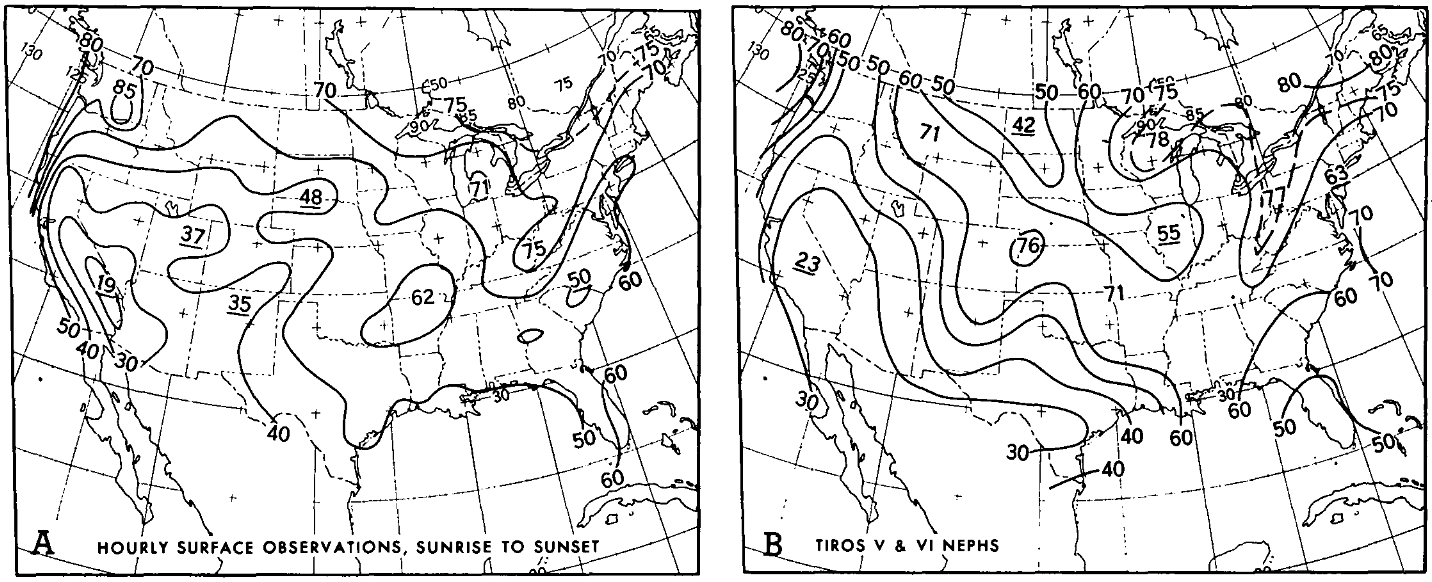

FIGURE 4.—Same as figure 2, for September–November 1962.

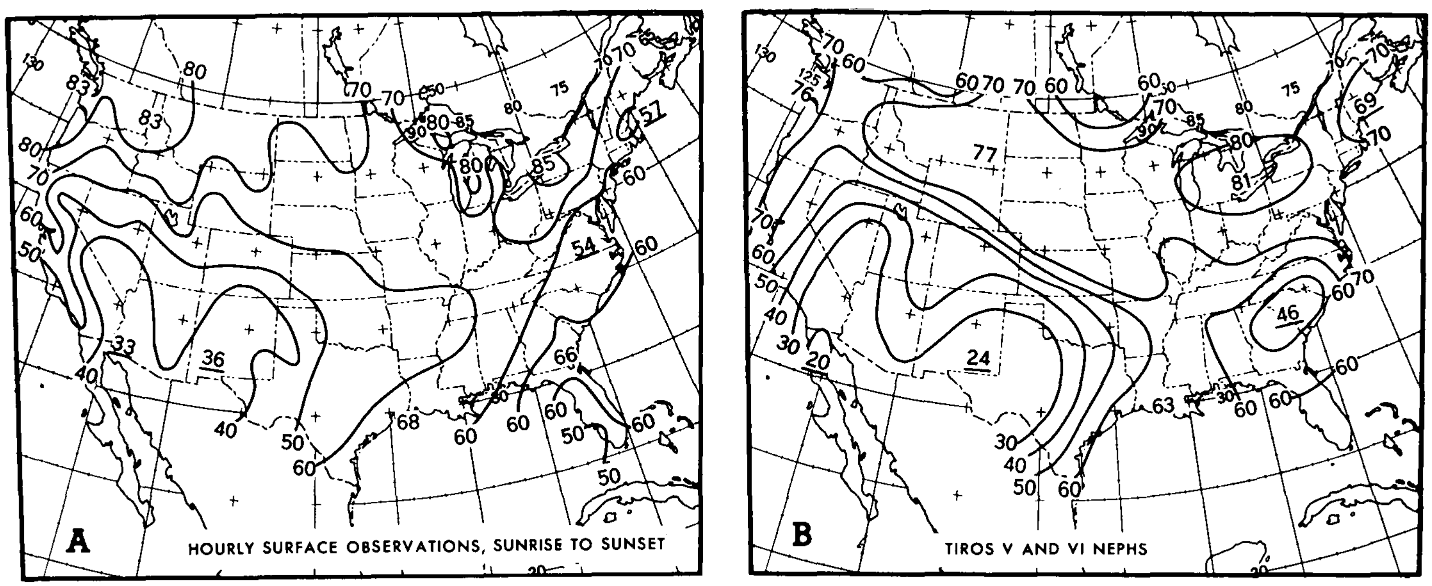

FIGURE 5.—Same as figure 2, for December–February 1962–63.

the regions of oceanic subtropical anticyclones. This suggests that this region might serve as an ideal landing area for future manned space capsules.

An outstanding difference in the two global patterns is the generally greater magnitude of cloudiness exhibited by the TIROS data in all major cloudy belts of the earth. This difference is so consistent, both in space and time, that undoubtedly it is due in part to errors in either or both the TIROS and normal data. Some discussion of errors will be taken up in the next subsection.

On the other hand, extremes of cloudiness should be expected to be greater for individual seasons than for a long-period normal. In fact, when the cloud patterns are examined in more detail, it is possible to show that the major departures from normal can logically be explained by corresponding anomalies of the general circulation. This possibility may be examined with the aid of the lower parts of figures 7 to 10, which contain the mean seasonal 700-mb. height contours and their departures from normal for the Northern Hemisphere north of 20° N.

The excessive cloudiness over northeastern Europe for the season March–May 1962 (fig. 7), was associated with unusually frequent cyclonic activity and rainfall, confirmed by European weather reports and suggested indirectly by the large negative mean seasonal height anomalies in that area. The abnormally low latitude of temperate-zone cloudiness in the North Pacific and Atlantic Oceans is associated with storm tracks displaced

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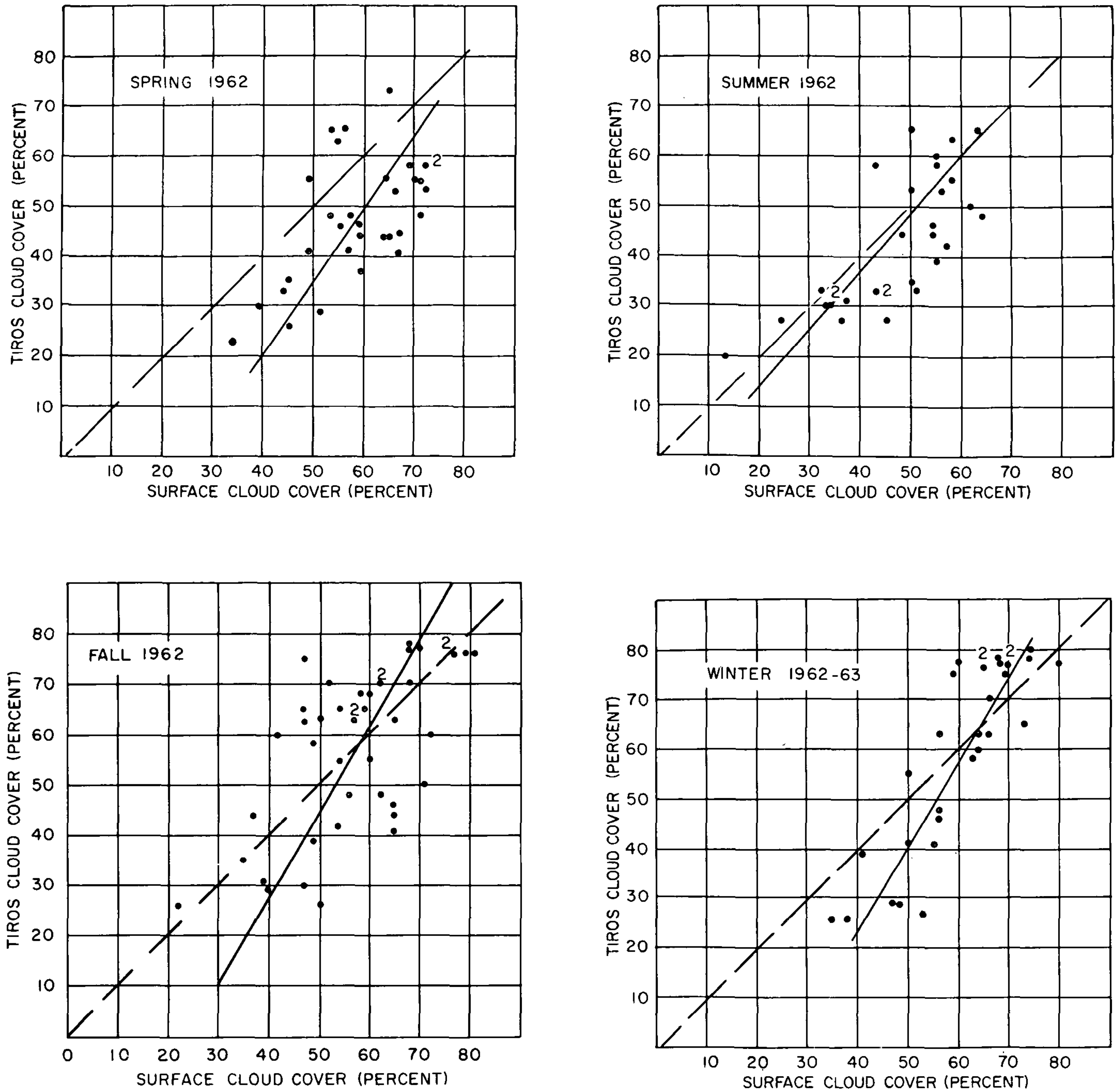

FIGURE 6.—Average daytime cloud cover from surface observations (in percent) vs. the corresponding TIROS averages, for each 5° latitude-longitude intersection over the United States and for each of the four seasons considered in this study. The number "2" indicates two observations at the same point. Line of perfect agreement is dashed. Axis of best fit to points (not regression line) is solid.

south of normal, as suggested by above-normal heights at high latitudes and below-normal heights at low latitudes in those oceans. It will be recalled that March 1962 was the month of the disastrous storm along the east coast of the United States (Posey [10]). That the blocking situation associated with that storm had apparently moved somewhat to the east by mid-season is suggested by the cloudiness and below-normal heights in the western Atlantic.

A feature more difficult to explain in the March–May period is the excessive cloudiness in the southern Bering Sea, located in the center of an anomalous anticyclone. Perhaps this is composed of stratus clouds formed in the moist air trapped below a low-level inversion caused by subsidence over the icy sea.

Height anomalies in June–August were generally small (fig. 8, lower). Nevertheless, an area of below-normal cloudiness extending from Spain to England and southern

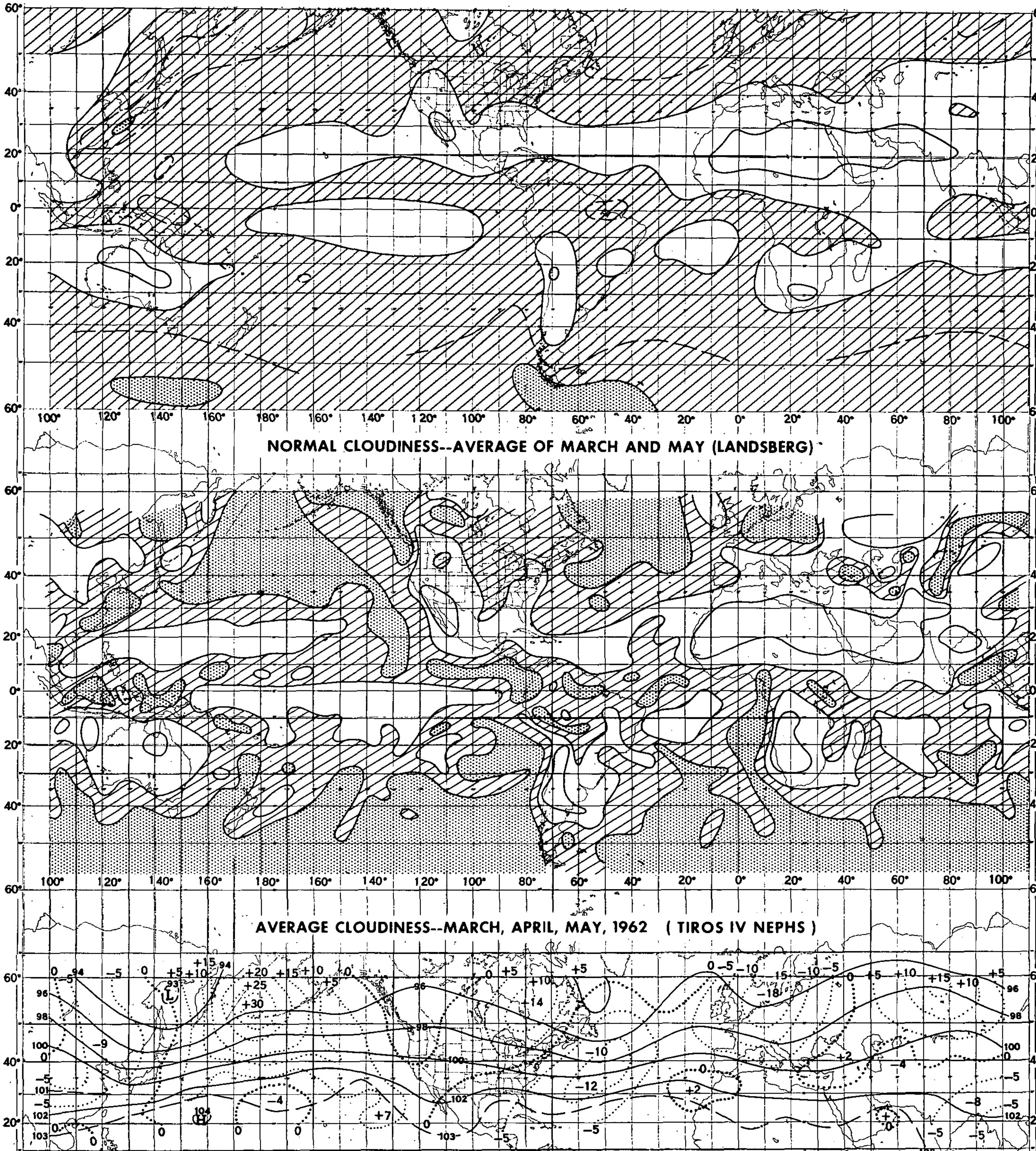

FIGURE 7.—(Middle) Global map of average daytime cloudiness from TIROS nephanalyses for March–May 1962. (Upper) Map of normal cloud cover averaged for March and May, after Landsberg [7], based on all available surface cloud observations for many years. Stippled shading, cloudiness greater than 75 percent sky cover; crosshatched, 50 to 75 percent; no shading, less than 50 percent. Isolines of 25 percent sky cover indicated by solid lines within white area and of 65 percent or 35 percent cover (where needed) by dashed lines. (Lower) Average seasonal 700-mb. height contours (solid lines) and departures from normal (dotted lines) for the Northern Hemisphere. Height contours are labeled in 100's of feet, anomalies in 10's of feet.

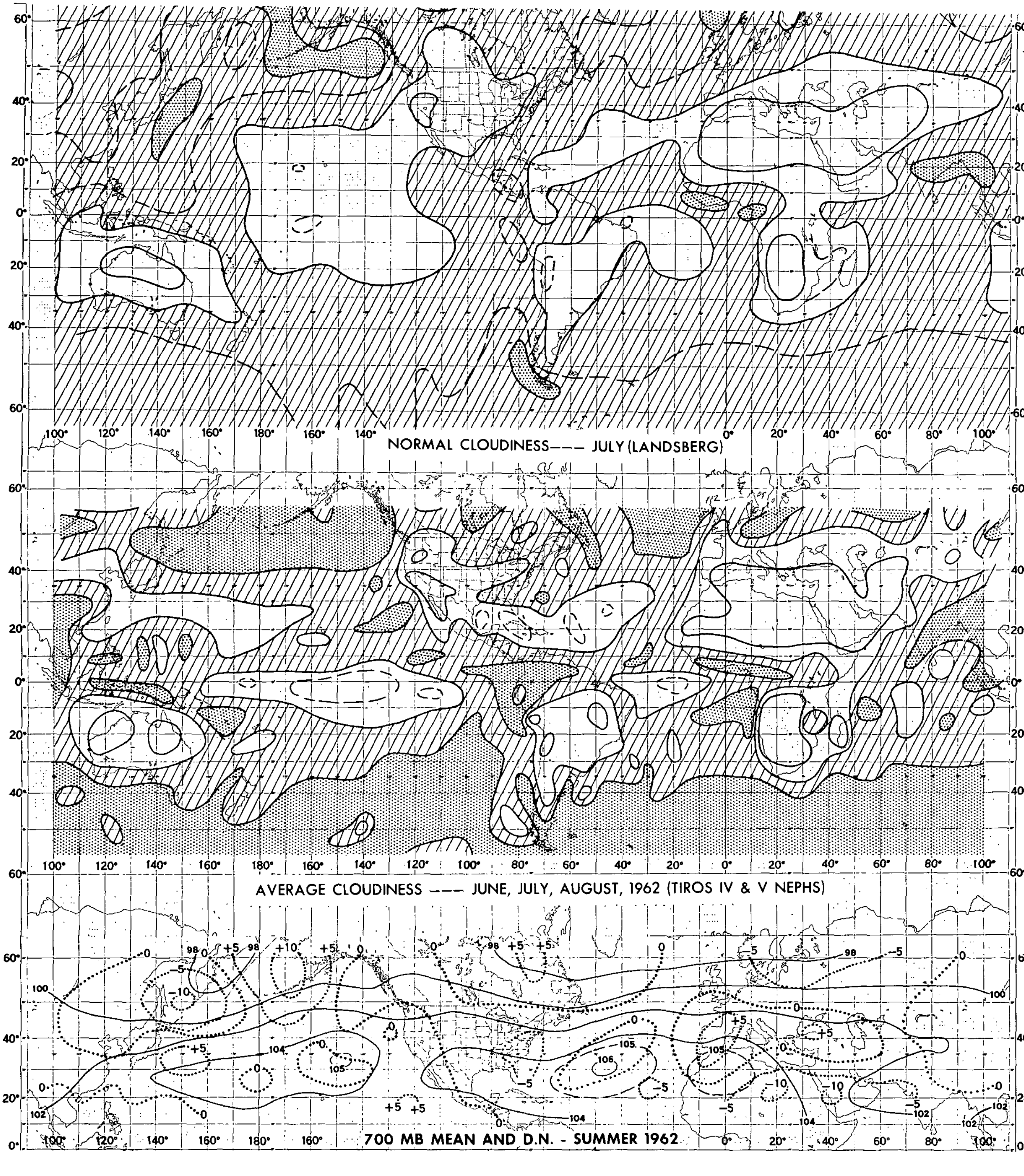

FIGURE 8.—(Middle) June–August 1962; (upper) July [7]; (Lower) June–August 1962. See legend to figure 7 for explanation.

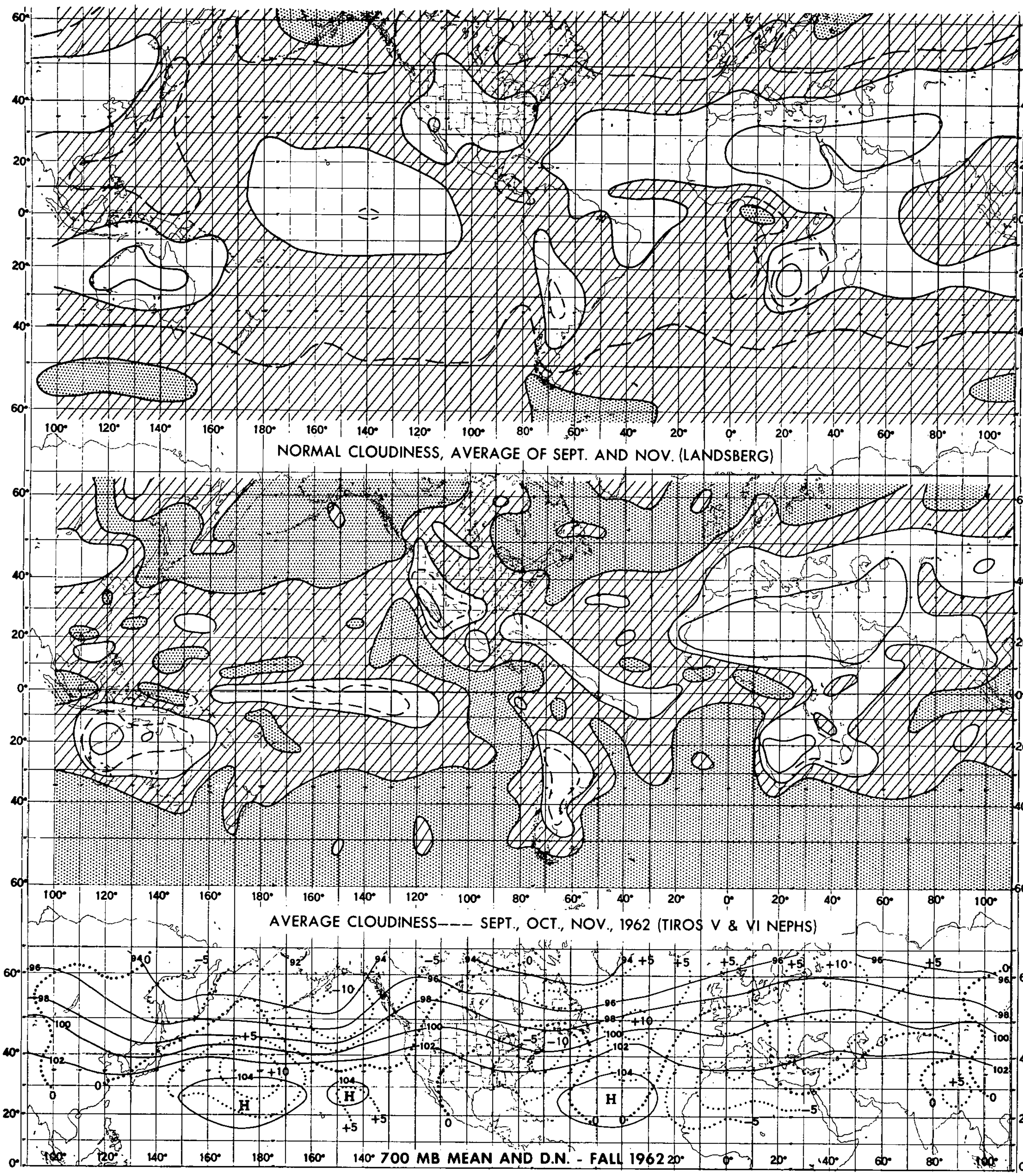

FIGURE 9.—(Middle) September–November 1962; (Upper) September and November [7]; (Lower) September–November 1962. See legend to figure 7 for explanation.

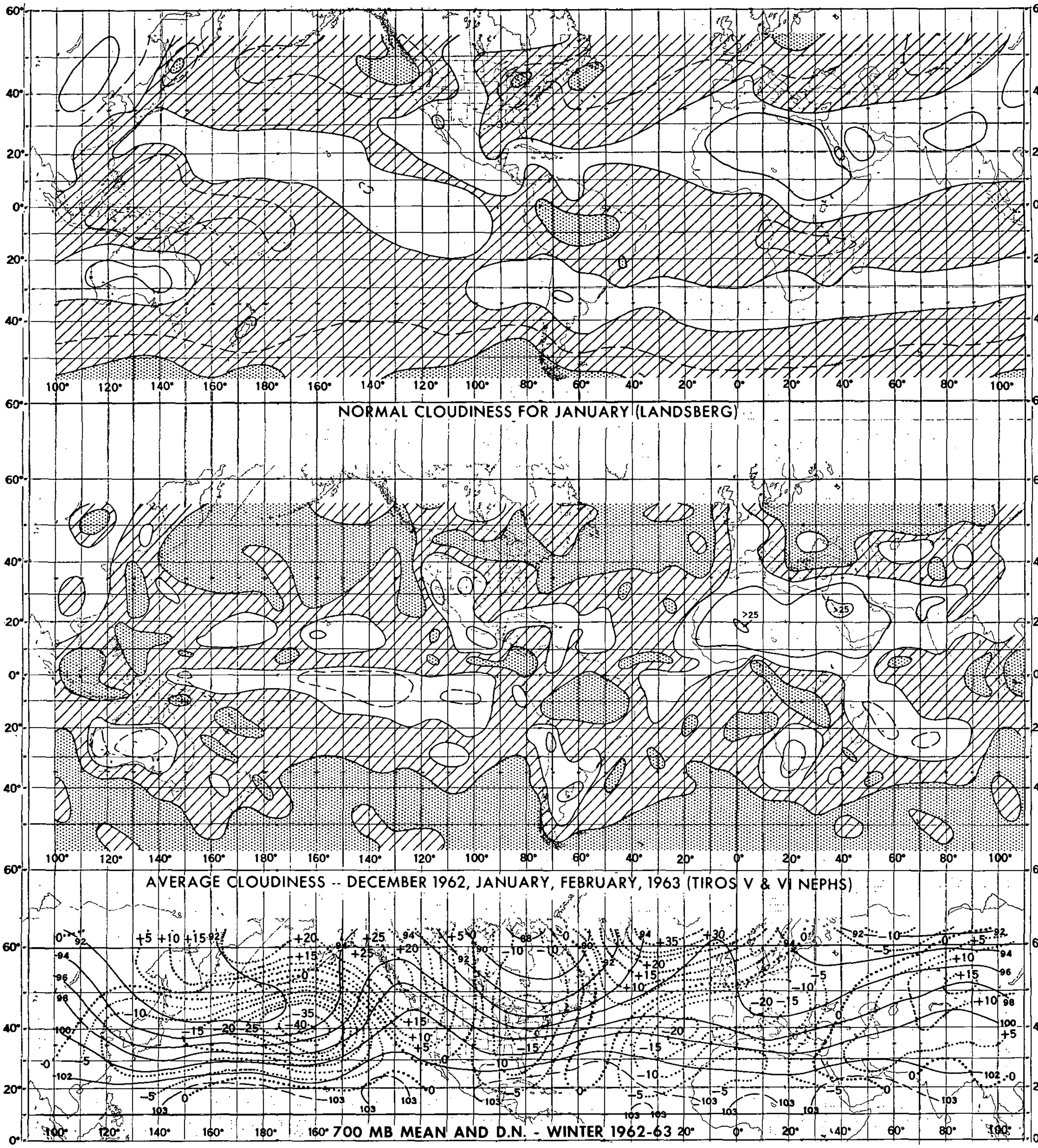

FIGURE 10.—(Middle) December 1962–February 1963; (Upper) January [7]; (Lower) December 1962–February 1963. See legend to figure 7 for explanation.

Scandinavia appears to have been associated with a region of above-normal anticyclonic activity and northerly flow. Above-normal cloudiness north of Japan was associated with an anomalous cyclone in that area.

In fall (fig. 9) below-normal cloudiness near the Black and Caspian Seas was in a region of anomalous anticyclonic activity, while above-normal cloudiness in northeastern North America lay north of a region of unusually persistent cyclonic activity. Greater-than-normal cloudiness in the central North Atlantic and North Pacific Oceans is difficult to explain in view of the anomalous anticyclonic activity in those areas. However, it may be noted that in all seasons there was a weak tendency for anomalous anticyclones over the sea to be associated with above-normal cloudiness, while the opposite was true over the land.

The winter of 1962–63 was unusually severe in most areas of the Northern Hemisphere (Andrews [4]). The Pacific, eastern Atlantic, and Europe were marked by southward displacement of the storm tracks (negative heights at low latitudes in the lower part of fig. 10) accompanied by cloudiness at unusually low latitudes and by a severe restriction in the area of small cloud amount in the oceanic subtropical anticyclones. On the other hand, in spite of the low-latitude storm tracks, it is surprising to find that the intertropical convergence zone in both oceans was farther north and accompanied by more cloudiness than normal.

MEAN LATITUDINAL CLOUD PROFILES

Figures 11 to 14 show zonally-averaged cloudiness as a function of latitude. The solid curve with circles gives the cloud cover derived from the TIROS nephanalyses. It is important to note that this was obtained by averaging the mean cloudiness used as the basis for figures 7 to 10, middle, rather than by recomputing a net mean cloudiness based on all data at a given latitude. In this way it was possible to avoid giving excessive weight to those localities having the greatest number of observations. Even with this precaution, some bias was introduced at those latitudes where a few latitude-longitude intersections have no observations at all.

The long-dashed curve with dots represents the normal cloud cover. The short-dashed curve with heavy dots for the June–August case (fig. 12) gives the mean cloudiness from July 12 to September 30, 1961, obtained by Arking [5] from TIROS III photographs; the dashed curve with crosses in figure 14 is the mean January cloudiness for the years 1922–55, based on observations from whaling ships (Vowinckel and van Loon [12]).

The major feature of these four latitudinal cloud profiles is the consistently higher values of cloudiness as compared to the normal counterparts. The consistency from season to season of the pattern of these differences is also striking, with the differences increasing with increasing average cloud amount and being much more pronounced in the Southern than in the Northern Hemisphere. Since it seems unreasonable to expect that the cloud cover should be so consistently anomalous throughout an entire year, one is naturally led to suspect systematic errors in one or both of the values.

In taking up the question of possible errors, we should recall (preceding subsection) that at least part of the anomaly at middle latitudes of the Northern Hemisphere in March–May and December–February is probably real, because oceanic blocking and low-latitude storm tracks, especially pronounced in winter, led to excessive cloudiness over large areas.

In considering possible sources of errors, one is struck by the fact that the differences shown in figures 11 to 14 are not consistent with the systematically *lower* values of TIROS-observed cloudiness in comparison with corresponding surface observations over the United States, where plentiful surface reports are available. Figure 6 shows that only when mean cloud cover exceeds 60 percent do the TIROS values average larger than the corresponding surface values, suggesting that "normal" cloudiness is systematically too low for intermediate cloud amounts. However, the study illustrated in figure 6 is based on daytime observations only, both for the TIROS and surface data, while the normal data also include nighttime cloudiness which tends to be less than that during the day. Therefore, part of the difference between the TIROS data and normal cloudiness may be due to this diurnal effect.

Other more recent estimates of normal cloudiness (which also include nighttime observations) are in somewhat better agreement with the TIROS data. These include unpublished normals based on more recent information over the oceans between 40° N. and 40° S. latitudes, kindly furnished to the author by the Weather Bureau's Spaceflight Meteorology Group. These new charts, for March and May (not illustrated), show more cloudiness in the North and South Pacific oceans (but not in the Atlantic) than that shown in the selected normal chart (fig. 7, upper). However, these amounts are also considerably less than the TIROS values.

Another bit of evidence of this sort is provided by mean January cloud charts for the years 1922 to 1955 at high latitudes in the Southern Hemisphere obtained from whaling-ship observations (Vowinckel and van Loon [12]). The latitudinal means of these observations, plotted in figure 14, are consistently higher than the selected normal values by 5 to 10 percent, but are again somewhat lower than the TIROS values.

The above evidence is counteracted by Arking's [5] mean cloud cover for July 12 to September 30, 1961 (fig. 12), obtained by photometric methods from individual TIROS III photographs. This shows good agreement in the Northern Hemisphere with the TIROS IV nephanalyses made one year later, but in the Southern Hemisphere Arking's values are much closer to the normals.

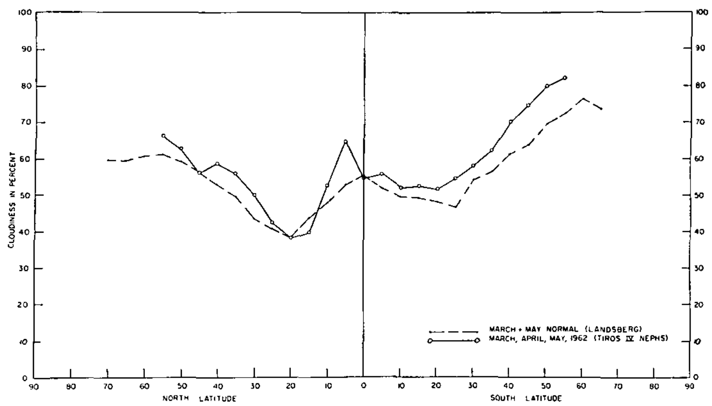

FIGURE 11.—Zonally-averaged cloudiness vs. latitude. Solid curve with open circles shows TIROS data March–May 1962; dashed curve with dots, normal data (March plus May) after Landsberg [7].

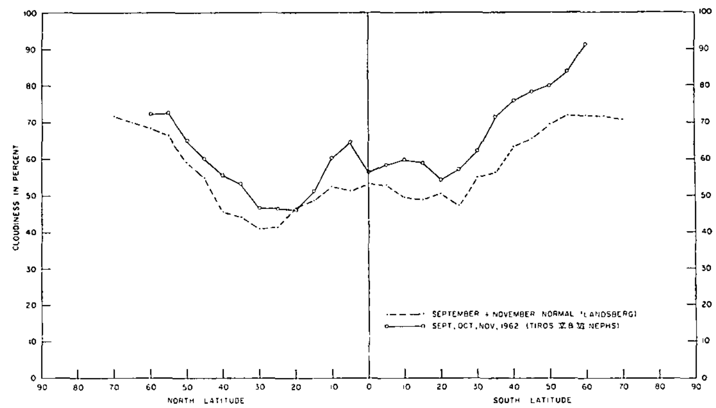

FIGURE 13.—Zonally-averaged cloudiness vs. latitude. Solid curve shows TIROS nephanalysis data, September–November 1962; dashed curve, normal data (September plus November) after Landsberg [7].

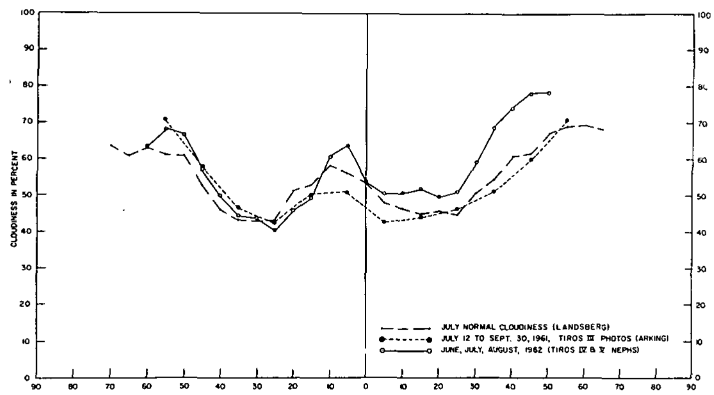

FIGURE 12.—Zonally-averaged cloudiness vs. latitude. Short-dashed curve with heavy dots gives TIROS III data for July 12 to September 30, 1961, after Arking [5]; dashed curve, normal data for July from [7]; and solid curve, TIROS V and VI data, June–August 1962.

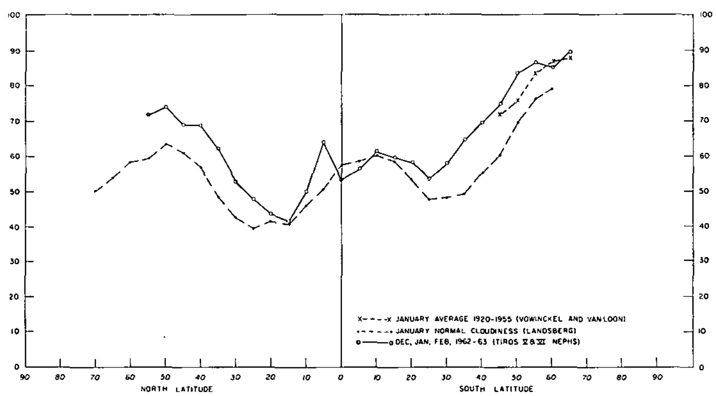

FIGURE 14.—Zonally-averaged cloudiness vs. latitude. Dashed line with crosses shows average January cloudiness, 1922–1955, from whaling ship reports, after Vowinckel and van Loon [12]; dashed line with solid dots, normal cloudiness for January, after Landsberg [7]; solid curve, TIROS data, December 1962–February 1963.

There are several possible sources of error in the TIROS cloud estimates. The limited resolving power of the television camera leads to an underestimate of low cloud amounts because of the failure to "see" scattered clouds of small horizontal scale. A recent study by Alder and Serebreny [3] shows that when the TIROS nephanalyses indicate no clouds, there may be as much as 20 percent low scattered cloud present. This may help account for the low TIROS values for small cloud cover, shown in figure 6. One would suspect that a similar type of error, but with opposite sign, becomes important as the true cloud amount approaches 100 percent, leading to an overestimate of high cloud amount through failure to resolve "holes" in the cloud deck. However, as far as is known, this possibility remains undocumented.

Another possible source of error lies in the oblique angle of the TIROS camera axis with respect to the vertical (closely related to the satellite nadir angle). It is clear that with large nadir angles a problem of perspective arises similar to the problem of a ground observer who attempts to estimate the amount of clouds near the horizon. In that case it is well known that there is a strong tendency to overestimate clouds of significant vertical thickness. It was thought, too, that this source of error might account for the systematically larger anomalies in the Southern Hemisphere than in the Northern Hemisphere, if it could be shown that the average nadir angle is larger in the Southern Hemisphere. To test this possibility, a sample, consisting of 10 percent of the nephanalyses for the March–May season, was selected and examined with respect to nadir angle. No systematic difference in nadir angle was found between the two hemispheres. Furthermore, in only 14 percent of the selected cases did the nadir angle reach the critical value of 64°, when the camera axis is pointing at the horizon. Finally, examination of the nephanalyses shows that only that part of a cloud photograph at a considerable distance from the horizon was used in their construction.

It is concluded that large nadir angles are not an important contributory cause of errors in the TIROS cloud estimates. This conclusion is supported by Arking's values, because, although these are obtained by a somewhat different procedure, they are subject to similar errors caused by poor resolution or large nadir angles. Yet they correspond closely to the normal values in both hemispheres.

Another source of error may be the existence of snow or ice cover, frequently indistinguishable from clouds. There is some evidence that this leads to an overestimate of cloudiness. Partly to counteract this effect, mean TIROS cloudiness has been omitted from figures 11 to 14 at latitudes higher than 55° in the winter, or cold, hemisphere.

To sum up, the meager observational evidence and crude analysis of errors presented above suggest that cloudiness amounts estimated from the TIROS pictures tend to be too large for large cloud amount and too small for low cloud amount, but information is too scanty to justify a quantitative estimate of the average errors.

4. CONCLUSIONS

It has been shown that in spite of a seemingly inadequate distribution of data in space and time, the series of cloud photographs from TIROS IV through VI, 1962–63, gives valuable global cloud patterns when the data are averaged for seasons. These patterns reveal not only the gross features characteristic of averages over many seasons (normal patterns), but also demonstrate an ability to delineate the major regions of abnormal cloudiness. This means that the large-scale features of the cloud distribution must possess a certain stability or repetitiveness over entire seasons, even in the regions of migratory cyclones and anticyclones.

It seems clear that the improved data coverage of the newer TIROS "wheel configuration" satellite and the Nimbus series will yield large-scale cloud patterns entirely adequate for general-circulation studies. Of course, cloud photographs will in time be supplemented or even replaced by interpretations of radiation measurements in various wavelength bands.

To make average global cloud information of immediate use to the practicing forecaster or even to the research meteorologist, it is obviously essential that the data be "digitalized" in some way, so that it can be rapidly stored on cards or magnetic tapes. These will then form the raw source material for all sorts of rapid electronic processing. This of course in the main weakness of the procedure used in this study, in which hand-processing of data for a single season took approximately 200 man-hours. The method proposed by Arking [5], while amenable to automation, has the severe drawback (fully realized by Arking) that the amount of light scattered from clouds (or any other surface) and registered on the photographs depends on many factors including solar zenith angle in the target region, satellite nadir angle, type of cloud, possible presence of specular reflection, and resolution and brightness contrast of the camera and photographic film. Until these problems are resolved through automation it should be fully understood that they can be overcome to a certain extent by the subjective judgment of an experienced meteorologist.

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